SPECIAL CONTRIBUTIONS.

THE PERIODICITY OF SUN SPOTS AND THE VARIATIONS OF THE MEAN ANNUAL TEMPERATURES OF THE ATMOSPHERE.

Note by M. CHARLES NORDMANN presented by M. H. POINCARÉ, translated from the Comptes Rendus. Paris, June, 1903. Tome 136, page 1047.

Since the well-known memoir by Koeppen,[1] which appeared in 1873, and which embraces the period from 1830 to 1870, no complete work on this subject has been published.

By the kind advice of Mons. H. Poincaré I have attempted to study the data for the past thirty years bearing on this question which is of such great importance to celestial phyiscs and meteorology. It results from Koeppen's work that the curve of the variations of mean annual temperatures pursues a regular course only at the tropical stations, and that for regions outside of the Tropics, this curve becomes so very irregular that it is no longer possible to recognize in it any periodic course whatever.

I have, therefore, only made use of the results at tropical stations. But as it is especially during these last thirty years that meteorological observations have been everywhere diffused and systematized, I have been able to utilize much more extensive and more accurate materials than Koeppen had at his disposal. For example, whereas, on the one hand, Koeppen only had access to observations from the Indies, the Antilles, and tropical America, I have been able to utilize those for a great number of stations distributed all around the globe, so that the results obtained can really be considered as representing the average condition of all that part of the earth situated between the Tropics; on the other hand, I have had at my disposal a series of observations generally longer for each station than those possessed by Koeppen, so that, whereas, he was obliged to make use of certain series containing only six years of observation (which might be a source of error) I was able to eliminate all series not having at least eleven years of observation, that is to say the mean value of a complete period of sun spots.

The stations, for which I have utilized all the observations published since 1870, are the following, in the order of increasing east longitude:

Havana, Cuba, north, 23°; west, 82°.
Kingston, Jamaica, north, 18°; west, 76°.
Port au Prince, Hayti, north, 18°; west, 72°.
Port of Spain, Trinidad, north, 11°; west 62°.
Pernambuco, Brazil, south, 8°; west, 35°.
Free Town, Sierra Leone, north, 8°; west, 13°.
Port Louis, Mauritius, south, 20°; east, 57°.
Rodriguez Island, south, 19°; east, 63°.
Bombay, India, north, 19°; east, 73°.
Batavia, Java, south, 6°; east, 107°.
Hongkong, China, north, 22°; east, 114°.
Zi-Ka-Wei, China, north, 31°; east, 121°.
Manila, Philippines, north, 11; east, 121°.

The following table summarizes the results obtained. Column A contains, for each year, the general mean of the annual deviations from the normal, and for all the stations; this series of means has been computed by giving the weight 2 to the observations at Bombay, Batavia, Zi-Ka-Wei, Hongkong, and Manila, whose means result from a great number of daily observations and extend over a greater number of years than those of the other stations; to these latter the weight 1 has been given. The figures in column B (calculated in order to give a more homogeneous appearance to the curve of the variations and to eliminate, as far as possible, the secondary irregularities from this curve), are computed in the following manner: Each figure of this column is equal to the mean of the corresponding number in column A and to the half sum of the figure which precedes and the figure which follows it. The column of sun spots contains opposite each year the relative numbers of spots (Wolf's numbers). The numbers in columns A and B represent hundredths of degrees centigrade:

Years.	A.	B.	Sun spots.
	°	°	
1870	—29	—22 min.	139 max.
1871	— 9	—14	111
1872	— 8	— 7	101
1873	— 4	— 9	66
1874	—22	—13	44
1875	— 6	—12	17
1876	—13	— 5	21
1877	+13	— 8	22
1878	+20	+13	3 min.
1879	0	+ 6	6
1880	+ 5	+11	32
1881	+33	+20 max.	54
1882	+ 3	+ 7	59
1883	— 9	—10	64 max.
1884	—27	—21 min.	63
1885	—20	—21	52
1886	—16	—17	25
1887	—16	— 5	13
1888	+26	+13	7
1889	+18	+15 max.	6 min.
1890	— 1	+ 6	7
1891	+10	+ 4	35
1892	— 1	— 5	73
1893	—27	—12 min.	84 max.
1894	+ 2	— 5	78
1895	+ 1	+ 7	64
1896	+25	+20	41
1897	+28	+25	26
1898	+19	+19	26
1899	+10	+18	12
1900	+33	+25 max.	9 min.

If we construct a curve by taking for abscisas the years and for ordinates the numbers in column B, and another curve by taking the same abscissas and as ordinates the numbers of the column Sun spots, but entering these latter ordinates negatively in such a way as to represent the inverse [strictly the complement] of the frequency of the sun spots, we obtain two curves of a perfectly parallel course. A more detailed discussion of the two curves only confirms their parallelism, which appears even in the most minute details; the limits of this note do not permit giving this detailed study here, but it will shortly appear in a memoir containing the details of this work.

We can, however, even now enunciate the following conclusion which results immediately from the examination of the preceding table.

The mean temperature of the earth is subject to a period substantially equal to that of the sun spots; the effect of these spots is to diminish the mean temperature of the earth; that is to say, the curve which represents the variations of the latter is parallel to the inverted curve of the frequency of the sun spots.

I take pleasure in expressing my profound gratitude to Monsieur Mascart who has kindly placed the resources of the Library of the Central Meteorological Bureau at my disposal for this investigation, and to Monsieur Angot who, with a kindness which I am happy to acknowledge, has given me the benefit of his advice, which is of much weight in these matter.

[1] Zeitschrift der Oesterr. Gesellschaft für Meteorologie, t. VIII, 1873.

ON THE SIMULTANEOUS VARIATIONS OF SUN SPOTS AND OF TERRESTRIAL ATMOSPHERIC TEMPERATURES.[1]

By Prof. ALFRED ANGOT, translated by Miss R. A. EDWARDS.

Mr. Charles Nordmann has recently published the general conclusions of a very interesting work in which, confirming and extending the results set forth by Koeppen thirty years ago, he shows the relation between the period of sun spots and the average annual temperature of the earth's atmosphere in the tropical regions.

To obtain this result Nordmann, as did Koeppen, took a cer-

[1] Annuaire de la Société Météorologique de France, June, 1903, pp. 93–97.

tain number of stations furnishing series of temperature observations for at least twelve years. For each station he took the general average and subtracted this average from the value corresponding to each year, which gave the departure of the year from the average. He then averaged the departures found for the different stations for the same year, giving a double weight to stations which afforded the longest series.

It seems to me that the departures thus obtained have no definite significance; it is very difficult, at any rate, to determine the degree of relation that they bear to each other. The average temperature of every station depends on the number of years employed; consequently the absolute values of the departures depend on the length of the series. Should there be, in the course of the same series, some modification of the observations resulting in lack of homogeneity, this defect would affect the general average and consequently all the departures.

Finally, the average of the departures for any given year (in Nordmann's column A) is not based on the same stations from one end of the series to the other.

Under these conditions, it appears to me that it would be advantageous to employ an altogether different method of discussion, in which the observations for each station are treated separately and by separate periods, corresponding nearly to those of the sun spots.

If the observations present some lack of homogeneity that can not be corrected, this defect will affect, at least, the results of one period only, namely, that in which the discontinuity occurs in the observations.

If, for a given station, the average annual temperatures (t) present a variation parallel to that of the number (r) of sun spots (the so-called relative number of Wolf), one can approximately express the relation by the formula

$$t = t_0 + a\,r, \tag{1}$$

(t_0) and (a) being two constants characteristic of each station and of each period of solar activity. Each year will furnish an analogous equation, so that a cycle of sun spots will give eleven equations, which will permit the determination of the most probable values of (t_0) and of (a). It is not necessary, however, that the cycle be absolutely complete; nine or ten years will be sufficient, providing they comprise the greatest and the least values of (r).

The most convenient and the most rapid process for solving the system of equations (1) is that of Cauchy.[2] We commence by adding the (n) equations; dividing the sum by (n), we obtain an equation of the form:

$$T = t + a\,R, \tag{2}$$

$$\text{in which } T = \frac{\Sigma t}{n} \quad R = \frac{\Sigma r}{n}.$$

We now subtract equation (1) from equation (2), or inversely, and obtain a number (n) of equations of the form:

$$a\,(r - R) = (t - T), \tag{3}$$

which we so arrange that the coefficient of (a) shall be always positive. The sum of these (n) equations, or

$$a\,\Sigma\,(r - R) = \Sigma\,(t - T),$$

gives the value of (a) in the most convenient manner possible. As an example of the method, I will here give the calculations relative to the ten years of observations (1892-1901) obtained at Camp Jacob (Guadeloupe). In the first series of equations the coefficient of (a) is the relative number (r) of sun spots, and the second member is the annual observed temperature (t), expressed in centigrade degrees. The second series of equations represents the equations (3) obtained by subtracting each of the first ten equations from their average.

[2] This is, of course, not equivalent to the solution by the method of least squares.—ED.

			C.	Departures.
		°C.	°C.	°C.
1892	$t_0 + 73\,a = 21.52$	$31.1\,a = -0.275$	21.51	+ 0.01
1893	$t_0 + 85\,a = 21.41$	$43.1\,a = -0.385$	21.40	+ 0.01
1894	$t_0 + 78\,a = 21.40$	$36.1\,a = -0.395$	21.47	− 0.01
1895	$t_0 + 64\,a = 21.63$	$22.1\,a = -0.165$	21.59	+ 0.04
1896	$t_0 + 42\,a = 21.83$	$0.1\,a = +0.035$	21.79	+ 0.04
1897	$t_0 + 26\,a = 22.02$	$15.9\,a = -0.225$	21.94	+ 0.08
1898	$t_0 + 27\,a = 21.82$	$14.9\,a = -0.025$	21.93	− 0.11
1899	$t_0 + 12\,a = 21.89$	$29.9\,a = -0.095$	22.06	− 0.17
1900	$t_0 + 9\,a = 22.19$	$32.9\,a = -0.395$	22.09	+ 0.10
1901	$t_0 + 3\,a = 22.24$	$38.9\,a = -0.445$	22.14	+ 0.10
Sum of 10 years	$t_0 + 419\,a = 217.95$	$263.0\,a = -2.370$		
Average	$t_0 + 41.9\,a = 21.795$	$a = -0.00901.$		

Substituting this value of (a) in the equation $t_0 + 41.9\,a = 21.795°$, we obtain $t_0 = 22.17°$.

If we calculate the temperature for each year by means of the formula $t_0 + ar$, we obtain the numbers given in column C in this table. Beside each of these numbers, we find the departures (obs. — calc.) between the temperatures as observed and as calculated.

The probable error of an observation calculated from the departures from the general average is $\pm 0.20°$ C.; it falls to $\pm 0.06°$ C. if we calculate it from the departures given in the last column of the table. It would seem then, according to these values, that the relation of the average temperatures to the sun spots at Camp Jacob is very clear. In addition, we notice that the value found for the coefficient (a) corresponds to a change of temperature of 0.90° C. (more than four times greater than the probable error of an observation) between the two years for which the difference between the relative number of sun spots is equal to 100, a difference which is sometimes exceeded when we compare years of maximum and minimum of sun spots.

In spite of this apparently favorable result, we should not conclude, from these observations alone, that the relation in question between temperature and sun spots actually exists; it is necessary to repeat the same calculation for a great number of stations and for many cycles of solar activity. Certain of these cycles will give a result favorable to the hypothesis, i. e., a negative value of the coefficient (a), others will give an unfavorable result; the ratio of the numbers of these two classes of cases will permit one to form an idea of the degree of probability as well as of the real size of the coefficient (a). I will not undertake here to discuss the question in a general manner. I will give only the results of some series that I have calculated, indicating for each series and each cycle the resulting equation for $a\,\Sigma\,(r - R) = \Sigma\,(t - T)$, which will give the value of (a).

Hongkong.—Two series of observations were obtained under different conditions, the one from 1865 to 1886 (1885 is missing) made by the military surgeons, and the other from 1884 to the present time, carried on at the observatory. These two series have been treated separately and divided each into two parts, ten years for the first series and nine for the second. The following are the resulting equations which give (a) for each of these four periods:

	°C.
1865-1874	$356\,a = -0.50$
1875-1886	$232\,a = -3.80$
1884-1892	$198\,a = -1.04$
1893-1901	$230\,a = -1.17$
	$1016\,a = -6.51$, whence $a = -0.0064°$ C.

The four periods considered are all favorable to the hypothesis of the relation between sun spots and temperatures.

Batavia.—The observations made at the observatory from 1866 to 1899 were divided into three periods, the first two of eleven years, the last of twelve; the resulting equations which give (a) are the following:

	° C.
1866–1876	$416\,a = -0.47$
1877–1887	$283\,a = -0.70$
1893–1899	$298\,a = -1.11$
	$952\,a = -2.28$, whence $a = -0.0024°$ C.

The three periods are again all favorable to the hypothesis, but the coefficient obtained is much smaller than for Hongkong.

Bombay.—The observations, made from 1846 to 1899, were divided into five periods, of which the first four comprise eleven years and the last ten years only. The equations which give (a) are the following:

	° C.
1846–1856	$330\,a = -2.37$
1857–1867	$263\,a = +1.23$
1868–1878	$423\,a = -0.10$
1879–1889	$240\,a = -0.47$
1890–1899	$240\,a = -1.02$
	$1496\,a = -2.73$, whence $a = -0.0018°$ C.

Of the five periods considered one is clearly unfavorable to the hypothesis; one gives scarcely any variation, and the other three are favorable.

Barbados.—Observations were made from 1865 to 1886, but as the two years 1881 and 1882 were missing, there remained then exactly twenty years which have been divided into two equal periods. The equations which give (a) are the following:

	° C.
1865–1874	$356\,a = -0.11$
1875–1886	$195\,a = +0.69$
	$551\,a = +0.58$, whence $a = +0.0011°$ C.

The first series is favorable to the hypothesis, the second unfavorable.

Havana.—Sixteen years of observations (1886–1901); using the years 1892–1895 twice, the two series are 1886–1895 and 1892–1901. The equations obtained for (a) are the following:

	° C.
1886–1895	$285\,a = -0.72$
1892–1901	$270\,a = -0.38$
	$555\,a = -1.10$, whence $a = -0.0020°$ C.

In summing up we find that of the 16 series thus studied, 14 give for (a) a negative value, 2 a positive value; the probability is then, according to these observations, 7 to 1 that an increase in the number of sun spots is accompanied by a diminution in the temperature and inversely.

By giving to the values of (a) deduced from observations of the various stations, weights proportional to the number of series, we obtain for a final value $a = -0.0033°$ C.

Hence, an increase of 100 in Wolf's relative sun-spot numbers (a difference which frequently exists between a maximum and a minimum) will be accompanied by a diminution of 0.33° C. in the value of the mean annual temperature.

It is evident that in order to determine the value of the coefficient (a) it would be necessary to work with a much larger number of series. I have given the numbers which precede only as an example of a method which appears to me more exact and more convincing than that ordinarily employed.

CLIMATOLOGY OF COSTA RICA.

Communicated by Mr. H. PITTIER, Director, Physical Geographic Institute.

[For tables see the last page of this REVIEW preceding the charts.]

Notes on the weather.—On the Pacific slope the rains were generally above the normal. In San José pressure and relative humidity were slightly above the average, while temperature was below. Sunshine 168 hours, against a normal of 134. On the Atlantic slope rains were also very abundant, excepting in the valleys of the interior, where there was a relative scarcity. A few local cyclonic movements did some damage to the banana plantations.

Notes on earthquakes.—August 8, 2^h 29^m a. m., slight shock, E–W, intensity II, duration 3 seconds. August 19, 1^h 02^m 50^s a. m., strong shock, WNW–ESE, intensity III, duration 3 seconds.

RECENT PAPERS BEARING ON METEOROLOGY.

Dr. W. F. R. PHILLIPS, Librarian, etc.

The subjoined titles have been selected from the contents of the periodicals and serials recently received in the Library of the Weather Bureau. The titles selected are of papers or other communications bearing on meteorology or cognate branches of science. This is not a complete index of the meteorological contents of all the journals from which it has been compiled; it shows only the articles that appear to the compiler likely to be of particular interest in connection with the work of the Weather Bureau. Unsigned articles are indicated by a ——.

Science. New York. N. S. Vol. 18.
Shedd, John C. Concerning the word Barometer. Pp. 279–280.
Ward, R. DeC. March Weather Proverbs. [Review of article of B. C. Webber.] P. 314.
Ward, R. DeC. Height of the Sea Breeze. [Note.] P. 314.
Ward, R. DeC. Storms of the Great Lakes. [Note on bulletin of E. B. Garriott.] Pp. 314–315.

Scientific American. New York. Vol. 89.
Talbot, Frederick A. The Spencer Airship for 1903. Pp. 169–170.
—— Experiments with motor-driven Aeroplanes. P. 204.
Guarini, Émile. The Seas of Fog. P. 207.

Scientific American Supplement. New York. Vol. 56.
Pressey, H. A. Methods of measuring velocity in river channels. Pp. 23140–23142.

Nature. London. Vol. 68.
—— Graham Bell's Tetrahedral Cell Kites. Pp. 347–349.
Ramsay, William and Soddy, Frederick. Experiments in Radio-Activity, and the Production of Helium from Radium. Pp. 354–355.
Strutt, R. J. On the Intensely Penetrating Rays of Radium. Pp. 355–356.
Geikie, Arch[ibald.] Summer Lightning. P. 367–368.
Wimperis, H. E. A Mirage at Putney. P. 368.
MacDowall, Alex. B. Sun Spots and Phenology. Pp. 389–390.
Walker, Alfred O. Peculiar Clouds. P. 416.
—— The International Study of the Sea. Pp. 417–418.

Proceedings of the Royal Society. London. Vol. 72.
Ramsay, William. Experiments in Radioactivity and the Production of Helium from Radium. Pp. 204–207.
Strutt, [R. J.] On the Intensely Penetrating Rays of Radium. Pp. 208–210.
Aitken, J. On the Formation of Definite Figures by the Deposition of Dust. [Abstract.] P. 211.

Symons's Meteorological Magazine. London. Vol. 38.
—— Heavy Falls of Rain in July, 1903. Pp. 113–114.
—— Abraham Follet Osler. P. 118.
—— Heavy Falls of Rain in short periods. Pp. 119–120.

Terrestrial Magnetism and Atmospheric Electricity. Baltimore. Vol. 8.
Pegram, G. B. On the Radio-Activity of Ground Air. [Review of article of J. Elster and H. Geitel.] P. 83.
Pegram, G. B. The Concentration of Radio-active Emanations in Liquid Air. [Review of article of H. Ebert.] Pp. 83–85.
Schultz, L. G. Messungen der Electricitätszerstreuung in der freien Luft. [Abstract of paper of J. Elster and H. Geitel.] Pp. 85–86.
Schultz, L. G. Étude de l'électricité atmosphérique au sommet du Mont Blanc, (4810 m.) par beau température. [Review of article of G. Le Cadet.] Pp. 86–87.
Schultz, L. G. Ueber Elektricitätszerstreuung bei nebeligem Wetter. [Review of article of A. Gockel.] Pp. 87–88.

American Society of Civil Engineers. New York. Vol. 29.
Johnson, Francis Robert. South African Irrigation. [Contains meteorological data.] Pp. 589–614.
Harrod, B. M.; Brown, L. W.; Ockerson, J. A.; Haupt, Lewis M. The Levee Theory on the Mississippi River. Pp. 690–739.

London, Edinburgh, and Dublin Philosophical Magazine. London. 6th Series. Vol. 6.
Petterson, J. On the Ionization in Air at different Temperatures and Pressures. Pp. 231–238.
Wilson, H. A. The Ionization produced by Hot Platinum in Air. Pp. 267–268.

Knowledge. London. Vol. 26.
Field, K. D. Curious Sunset Phenomena. Pp. 206–207.